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Review

TOSSIM and distributed binary consensus algorithm in wireless sensor networks

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ABSTRACT

In this paper, we present distributed binary consensus algorithm over the wireless sensor networks (WSN) in the presence of faulty nodes. We assume that each fault occurs during the execution of an algorithm on a sensor node. With binary consensus, each sensor node, initially, observes one of two states TRUE and FALSE and the aim is to decide which one of the two states was held by the majority of the nodes. The nodes exchange their measurements and each one updates its state according to the state communicated by the last contacted node. We propose the implementation of the distributed binary consensus algorithm in WSN when the network contains *t* faulty nodes. The implementation was tested on sensor nodes using the TinyOSSimulator (TOSSIM) for a WSN with a large number of nodes. This ensures that the simulation is more close to the real environment. It also guarantees that the code performs correctly when deployed on the physical nodes. In order to evaluate the performance of the distributed system, we consider the analysis of the average convergence time over a simulated environment such as TOSSIM and considering the presence of malicious nodes. These results are presented for a WSN with different topologies such as fully connected, path, ring, Erdos Reny random, and star-shaped.

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1. Introduction

Distributed computations within wireless sensor networks (WSNs) are currently of great interest to engineers and researchers. The significant challenge in this field is to seek how we can achieve the overall reliability of the whole network in the face of faulty nodes. The consensus problem is related to the distributed manipulation of a single data within the nodes of the network (Bashir et al., 2006; Avrachenkov et al., 2011; Chen et al., 2011).

Bashir et al. (2006) use consensus algorithm to provide a powerful solution for distributed routing failure detection in WSN. Indeed, a consensus about suspected node is generated by the collaboration of neighbor nodes. A simple algorithm for consensus is presented; every neighbor node considers a decision factor for every other neighbor in order to generate a unified agreement about the node under suspicion. In their work Bashir et al. analyze and show that their approach performs better for energy conservation and node lifetime than the previous methods. However, their approach is limited to a network with a specific tree around the suspected node, and its mechanism is more close to the well-known voting method.

The authors in Avrachenkov et al. (2011) proposed a new average consensus algorithm, where each node selects its own weights based on some local information about the neighbors. The proposed algorithm is tailored for network with clusters structure. The neighborhood algorithm is designed to identify such links and gives them higher weights in order to speed-up information propagation among different parts of the network. In realistic sensor network topologies, the algorithm shows faster convergence than other existing consensus protocols. The authors in Chen et al. (2011) present an iterative decentralized consensus algorithm for routing in WSN by considering the minimization of the number of iterations which ensures the limitation of the energy consumption.

Binary consensus algorithm is a sub-scale of consensus problem and it is applied when there is delimitation on the memory and on the processing speed (Mostefaoui et al., 2000; Perron and Vasudevan, 2009; Braca et al., 2008, 2010; Bajovic et al., 2011; Cattivelli and Sayed, 2011). In a binary consensus algorithm, all nodes initially compute a TRUE or FALSE answer to a given question (such as whether the current temperature is over 35 °C) and then attempt to reach agreement on which state the majority of nodes hold. Mostefaoui et al. (2000) proposed a reduced complexity algorithm in asynchronous systems with crash failures. In their algorithm, each process runs a series of binary consensus subroutines in order to solve multivalued consensus. Nevertheless, the number of subroutines necessary to solve one multivariate consensus instance is unlimited and depends on the message delay.

In Braca et al. (2008, 2010), the authors study the behavior of a WSN, where the nodes continuously sense the surrounding environment and the observations are averaged over different sensor nodes. They are based on the fact that the arithmetic mean of the observations is time varying. Here, the averaging method uses an updating rule which is a closed form equation. Braca et al. (2010) investigate the asymptotic properties of running consensus detectors both under the Neyman–Pearson paradigm (fixed number of data) and in the sequential case. They developed an appropriate asymptotic framework, and they provided exact theoretical results, showing the asymptotic optimality of the running consensus detector. As in Braca et al. (2008), the authors use a closed form of updating rules which is limited to analog values of the observations.

In Cattivelli and Sayed (2011), the authors study the problem of distributed detection. They seek for fully distributed and adaptive implementations, where all nodes make individual real-time decisions by communicating with their immediate neighbors. Their proposed algorithms are adaptive and can track changes. Probability of detection and of false alarm are analyzed and compared with other centralized schemes. In their system each node communicates with its neighbors only and this ensures a consensus between some neighbors nodes only.

In Wang and Djuric (2013) the authors study the problem of distributed hypothesis testing in cooperative networks of agents. In their system, the agents try to reach consensus on the state of nature based on their private signals and on the binary actions of their neighbors. Specifically the authors propose a set of gossip-type methods for which two communicating agents reach the optimal local consensus with probability one by exchanges of binary actions at every time slot. The authors prove that the decision of each agent converges in probability to the optimal consensus. The authors also derive analytical results that relate the convergence rate of the algorithm and the weight matrix used in selecting the agents for gossiping.

In Penna et al. (2011) the authors propose a uniformly reweighted Belief Propagation (BP) scheme that reduces the impact of cycles by weighting messages by “edge appearance probability” $\rho \leq 1$. They apply this algorithm to distributed binary hypothesis testing problems in wireless networks with Markov random field models. The authors demonstrate that the proposed method outperforms standard BP, while maintaining similar complexity. They show also that the optimal can be approximated as a function of the average node degree, and can be computed in a distributed fashion through a consensus.

In Lindberg et al. (2013), the authors employ distributed particle filtering in target tracking applications, where many sensors must have a common view of the target's state. Specifically, the authors study the delay/performance trade-off of distributed particle filtering with belief consensus in the presence of time division medium access control. The authors compute local weight and use average weight consensus in each sensor to compute common weights. The consensus is based on the analog values of the local wight.

In Draief and Vojnovic (2010), the authors derived an upper-bound of the expected convergence time of the distributed binary consensus algorithm. The bound is derived for a particular network topology with a fully connected topology. In addition, they instantiated the upper-bound for some other network topologies such as complete graph, star-shaped, ring and Erdos–Renyi random graph. However, the contribution of Draief et al. is limited to the mathematical aspect of the problem without the consideration of the real conditions of the application such as communication protocols and routing in WSN. Indeed, the average convergence time depends also on the implementation and tests conditions of the binary consensus algorithm over the simulation and testbed framework.

In this paper, we extend the work of Draief and Vojnovic (2010) by considering the following main points: (1) design and implement the binary consensus algorithm given by Draief in real wireless sensor network testbed under Tinyos environment and with the presence of faulty nodes (Levis et al., 2003; Demmer and Levis, 2004; Notani, 2008; Safaei and Ismail, 2012). (2) Explore the results in a complete experimental environment by considering the routing and packet acknowledgments for fully connected, star-shaped and ring topologies. (3) Prove that our results, given for perfect communication channel and distributed manner, are close to the analytical results obtained by Draief.

The remainder of the paper is organized as follows. In Section 2, we present the binary consensus algorithm. Section 3 details the design and implementation of binary consensus algorithm on WSN. Section 4 presents the testbed environment and the hardware emulation tools based on TinyOS operating system. The hardware emulations as well